

October 26, 2004

U. S. Nuclear Regulatory Commission  
ATTN: Document Control Desk  
Washington, DC 20555-0001

Subject: **Docket No. 50-362**  
**Third Ten-Year Inservice Inspection (ISI) Interval Relief Request**  
**ISI-3-13 Request to Use Alternative To ASME Code Rules For**  
**The Embedded Flaw Repair Process for Reactor Vessel Head**  
**Penetration 56**  
**San Onofre Nuclear Generating Station Unit 3**

Dear Sir or Madam,

This letter submits the Southern California Edison (SCE) Company's Relief Request ISI-3-13 to allow the use of the embedded flaw repair process as an alternative to the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code Process for the as-found configuration of Reactor Vessel Head Penetration (RVHP) 56.

SCE intends to use the embedded flaw repair process on RVHP 56 as described in relief request ISI-3-8, supplemented by letter from A. E. Scherer (SCE) to the Document Control Desk dated March 15, 2004, and approved by letter from Stephen Dembeck (NRC) to A.E. Scherer (SCE) dated May 5, 2004. The characteristics of the indication in RVHP 56 however are not bounded by the evaluation and analysis previously submitted in support of ISI-3-8. Therefore, the enclosed relief request ISI-3-13, which includes an analysis supporting the characteristics of RVHP 56, is being submitted for U.S. Nuclear Regulatory Commission (NRC) review and approval.

To assist in your review, change bars are used to indicate differences between ISI-3-8 and ISI-3-13. Although the discussions related to inside diameter (I.D.) repairs were not deleted from the discussion, SCE will utilize the outside diameter (O.D.) repair process to repair RVHP 56.

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SCE requests NRC approval of Relief Request ISI-3-13 prior to Mode 4 entry. SCE will keep the NRC Project Manager for SONGS Units 2 and 3 informed, as the outage schedule is finalized.

Should you have any questions, please contact Mr. Jack Rainsberry at (949) 368-7420.

Sincerely,

A handwritten signature in black ink, appearing to read "B. S. Mallett". The signature is fluid and cursive, with the first letters of the first and last names being capitalized and prominent.

Enclosure

cc: B. S. Mallett, Regional Administrator, NRC Region IV  
B. M. Pham, NRC Project Manager, San Onofre Units 2, and 3  
C. C. Osterholtz, NRC Senior Resident Inspector, San Onofre Units 2 and 3

**ENCLOSURE**

**Relief Request ISI-3-13**

**Request To Use Alternative To ASME Code Rules  
For The Embedded Flaw Repair Process  
On SONGS Unit 3  
Reactor Vessel Head Penetration 56**

**Proposed Alternative**  
**In Accordance with 10 CFR 50.55a(a)(3)(i)**

**Alternative Provides Acceptable Level of Quality and Safety**

**1.0 ASME Code Components Affected**

The affected component is the San Onofre Nuclear Generating Station (SONGS) Unit 3 reactor vessel head penetration (RVHP) 56. All reactor pressure vessel head (RPVH) penetrations are American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Class 1 components.

**2.0 Applicable Code Edition and Addenda**

Reactor Vessel Construction Code, ASME Section III, 1971 Edition, through the Summer 1971 Addenda

Code of Record for Current (Third) Ten-Year Inservice Inspection (ISI) Interval, ASME Section XI, 1995 Edition, through the 1996 Addenda

**3.0 Applicable Code Requirements**

ASME XI, IWA-4410(a) states the repair/replacement activities, such as metal removal and welding, shall be performed in accordance with the Owner's Requirements and the original Construction Code of the component or system. The applicable Construction Code is ASME III, 1971 Edition, through the Summer 1971 Addenda.

**BASE METAL DEFECT REPAIRS**

ASME III, NB-4131 states that defects in base metals, such as the RPVH penetration tubes, may be eliminated or repaired by welding, provided the defects are removed, repaired and examined in accordance with the requirements of NB-2500.

ASME III, NB-2538 addresses elimination of base material surface defects and specifies defects are to be removed by grinding or machining. Defect removal must be verified by a magnetic particle or liquid penetrant examination using acceptance criteria of NB-2545 or NB-2546. If the removal process reduces the section thickness below the NB-3000 design thickness, then repair welding per NB-2539 is to be performed.

### **3.0 Applicable Code Requirements (continued)**

ASME III, NB-2539.1 addresses removal of defects and requires defects be removed or reduced to an acceptable size by suitable mechanical or thermal methods.

ASME III, NB-2539.4 provides the rules for examination of the base material repair welds and specifies they shall be examined by the magnetic particle or liquid penetrant methods with acceptance criteria per NB-2545 and NB-2546. Additionally, if the depth of the repair cavity exceeds the lesser of 3/8" or 10% of the section thickness, the repair weld shall be examined by the radiographic method using the acceptance criteria of NB-5320.

#### **WELD METAL DEFECT REPAIRS**

ASME III, NB-4451 states defects in weld metal shall be eliminated and, when necessary, repaired per NB-4452 and NB-4453.

ASME III, NB-4452 addresses elimination of weld metal surface defects and specifies defects are to be removed by grinding or machining. Defect removal must be verified by a magnetic particle or liquid penetrant examination using acceptance criteria of NB-5340 or NB-5350. If the removal process reduces the section thickness below the NB-3000 design thickness, then repair welding per NB-4453 is to be performed.

ASME III, NB-4453.1 addresses removal of defects in welds and requires the defect removal be verified with magnetic particle or liquid penetrant examinations using acceptance criteria of NB-5340 or NB-5350, or in the case of partial penetration welds where the entire thickness of the weld is removed, and only a visual examination is required.

#### **REQUESTED RELIEF**

Relief is requested from the requirements of ASME XI, IWA-4410(a), to perform repairs on the RPVH penetrations per the rules of Construction Code.

Relief is requested from the requirements in ASME III, NB-4131, NB-2538 and NB-2539.1 to eliminate base material defects prior to repair welding.

### **3.0 Applicable Code Requirements (continued)**

#### **REQUESTED RELIEF**

Relief is requested to use substitute examination methods in lieu of those specified in NB-2539.4 for the following cases:

- In the case of embedded flaw welds on the ID surface of the penetration tubes, eddy current and ultrasonic examinations will be performed on the overlay repair welds which are surface and volumetric examinations but are different methods than specified in NB-2539.4.
- In the case of embedded flaw welds on the OD surface of the penetration tubes, surface examinations using the liquid penetrant method will be performed on the overlay repair weld surface. Additionally, ultrasonic examinations of the repair weld volume will be performed from the ID surface opposite the overlay repair weld. The ultrasonic method is a different volumetric examination method than is specified in NB-2539.4.

Relief is requested from the requirements in ASME III, NB-4451, NB-4452 and NB-4453.1 to eliminate weld metal defects prior to repair welding.

### **4.0 Reason for the Request**

Southern California Edison (SCE) Company performed RPVH penetration inspections during the Unit 3 Cycle 13 refueling outage to meet the requirements of the First Revised NRC Order EA-03-009 (Reference 1). Results of the inspection will be sent within 60 days after returning the plant to operation following the end of the Unit 3 Cycle 13 refueling outage via separate submittal in accordance with the requirements of Reference 1.

During the inspection, an indication was found in RVHP 56 that will be repaired during the current refueling outage using the embedded flaw repair process. However, the characteristics of the indication in RVHP 56 are not covered by the evaluation and analysis that support the previously approved Safety Evaluation Report (SER) on embedded flaw repair (Westinghouse Topical Report WCAP-15987-P, Revision 2, Reference 2).

#### **4.0 Reason for the Request (continued)**

Specifically, the measured depth of the indication in RVHP 56 is 78 percent through wall, which exceeds the allowable flaw size of 75 percent through wall described in section C.4.2 of the Topical Report (Reference 2). As a result, a revised allowable flaw size of 89 percent through wall has been calculated in accordance with ASME Code, Section XI, paragraph IWB 3640 for the specific service conditions applicable to RVHP 56. Post repair crack growth calculation methodology is unchanged from the methodology previously approved in the SER for ISI-3-8 (Reference 5).

The proposed embedded flaw process as described in the May 16, 2003 letter from Westinghouse to the NRC (Reference 2), NRC Safety Evaluation Report which approved the Westinghouse embedded flaw process (Reference 3), the October 1, 2003, letter from Westinghouse to the NRC (Reference 4), and the supplemental analysis attached to this relief request provides an acceptable alternative to repair RVHP 56.

#### **5.0 Proposed Alternative and Basis for Use**

##### **PROPOSED ALTERNATIVE**

Design, implementation of repairs, and inspections will be consistent with the information contained in References 2, 3, 4, and the attached "Evaluation of the Acceptability of Embedded Flaw Repair of the Indication in Reactor Vessel Head Penetration No. 56 at SONGS Unit 3."

- The embedded flaw repair overlay welds on the penetration J-groove welds will consist of a minimum of 3 deposited layers.
- The embedded flaw repair overlay welds on the inside diameter (ID) and the outside diameter (OD) of the penetration tube material will consist of a minimum of 2 deposited layers of weld, consistent with Reference 4, to minimize welding induced residual stresses and material distortion. In the case of repairs on the ID surface, the 2 layer approach results in a reduced inlay excavation depth.

##### **BASIS FOR USE**

In the NRC Safety Evaluation Report (SER) (Reference 3) the NRC staff concluded that, subject to the conditions of the SER, the embedded flaw process proposed provides an acceptable level of quality and safety.

**5.0 Proposed Alternative and Basis for Use (continued)**

**BASIS FOR USE (continued)**

SCE has performed a Code reconciliation to verify that the bases contained in WCAP-15987-P Revision 2 are applicable to the SONGS Units 2 and 3. The referenced July 3, 2003, Safety Evaluation (Reference 3) found WCAP-15987-P Revision 2 to be acceptable for referencing in licensing applications as an alternative to the 1989 Edition of Section III of the ASME Code, with limitations noted in the SER. The SONGS Code reconciliation was performed in accordance with the SONGS ASME XI Program between the applicable repair requirements of ASME III, 1989 Edition and ASME III, 1971 Edition, Summer 1971 Addenda (construction code of record for the SONGS reactor vessels) and the differences identified were suitably reconciled.

In both cases of the ID and the OD overlay repair welds, the proposed substitute examination methods have been previously demonstrated to be adequate for flaw detection and sizing as shown in Reference 4.

The embedded flaw repair process is considered a permanent repair that will last through the useful life of the RPVH. As long as a primary water stress corrosion cracking (PWSCC) flaw remains isolated from the primary water environment the only known mechanism for any further potential propagation is fatigue. The calculated fatigue usage in this region is very low, because the reactor vessel head region is isolated from the transients that affect the hot leg or cold leg piping.

The thickness of the weld used to embed the flaw has been set to provide a permanent embedment of the flaw. The embedded flaw process imparts less residual stresses than weld repair following the complete removal of the flaw.

Since Alloy 52 (690) weldment is considered highly resistant to PWSCC, a new PWSCC crack should not initiate and grow through the Alloy 52 overlay to reconnect the primary water environment with the embedded flaw. The resistance of the alloy 690 material has been demonstrated by laboratory testing, and in approximately 10 years of operational service in steam generator tubes, where no PWSCC has been found.

**5.0 Proposed Alternative and Basis for Use (continued)**

**BASIS FOR USE (continued)**

As previously discussed, an additional analysis was performed using the same methodology as the Topical Report to evaluate and analyze RVHP 56 for an embedded flaw repair. The results of this analysis demonstrate that an embedded flaw repair on RVHP 56 will meet ASME Section XI Code requirements for allowable flaw size until the end of the SONGS Unit 3 third ten-year inspection interval (August 17, 2013). A copy of the analysis "Evaluation of the Acceptability of Embedded Flaw Repair of the Indication in Reactor Vessel Head Penetration No. 56 at SONGS Unit 3" is attached.

Future inspections of this nozzle will be performed to meet the NRC Order (Reference 1) and will be consistent with the requirements specified in section 4.0 of Reference 5 for vessel head penetration nozzle O.D. repairs below the J-groove weld. Inspections will be performed each refueling outage and the results will be included in the 60-day post refueling outage report required by Reference 1.

Therefore, the embedded flaw repair process is considered to be an alternative to Code requirements that provides an acceptable level of quality and safety, as required by 10 CFR 50.55a(a)(3)(i).

**6.0 Duration of Proposed Alternative**

Relief is requested for the third in-service inspection interval at SONGS Units 2 and 3, which is scheduled to end on August 17, 2013.

**7.0 Precedents**

Letter from Stephen Dembeck (NRC) to G.R. Overbeck (APS) dated, September 25, 2003; Subject: "Palo Verde Nuclear Generating Station, Units 1, 2, and 3, - Relief Request NOS. 20 and 21 Re: Alternatives to Inservice Inspection Program Flaw Repair Requirements (TAC NOS. MB4498, MB4499, MB500, MB4645, MB4646, and MB4647)"

Letter From Richard J. Laufer (NRC) to L.W. Pearce (FENOC) dated May 14, 2003; Subject: "Beaver Valley Power Station, Units 1 and 2 – Evaluation of Inservice Inspection (ISI) Relief Request BV3-RV-04 (TAC Nos. MB8172 and MB8173)"

Letter From Stephen Dembeck (NRC) to A.E. Scherer (SCE) dated May 5, 2004; Subject: San Onofre Nuclear Generating Station, Units 2 And 3, Inservice Inspection Program Relief Request ISI-3-8, Embedded Flaw Repair Process (Tac Nos. Mc1470 And Mc1471)

## **8.0 References**

1. U. S. Nuclear Regulatory Commission (NRC) First Revised NRC Order EA-03-009 Establishing Interim Inspection Requirements for Reactor Pressure Vessel Heads at Pressurized Water Reactors," dated February 20, 2004
2. Letter from H. A. Sepp (Westinghouse) to the Document Control Desk (NRC) dated May 16, 2003; Subject: Request for Review and Approval Westinghouse Topical Report WCAP 15987-P, "Technical Basis for the Embedded Flaw Process for Repair of Reactor Vessel Head Penetrations" (Proprietary) and WCAP-15987-NP (Non-proprietary)
3. Letter from H. N. Berkow, (NRC) to H. A. Sepp, (Westinghouse) dated July 3, 2003; Subject: "Acceptance for Referencing – Topical Report WCAP 15987-P, Revision 2, "Technical Basis of the Embedded Flaw Process for Repair of Reactor Vessel Head Penetrations, (TAC No. MB8997)"
4. Letter LTR-NRC-03-61 from J. S. Galembush (Westinghouse) to Terrence Chan (NRC) and Bryan Benney (NRC) dated October 1, 2003; Subject: "Inspection of Embedded Flaw Repair of a J-groove Weld"
5. Letter From Stephen Dembeck (NRC) to A.E. Scherer (SCE) dated May 5, 2004; Subject: San Onofre Nuclear Generating Station, Units 2 And 3, Inservice Inspection Program Relief Request ISI-3-8, Embedded Flaw Repair Process (Tac Nos. Mc1470 And Mc1471)

## **ATTACHMENT**

**Relief Request ISI-3-13**

**Evaluation of the Acceptability of Embedded Flaw Repair  
of the Indication in Reactor Vessel Head Penetration No. 56  
at SONGS Unit 3**

# **Evaluation of the Acceptability of Embedded Flaw Repair of the Indication in Reactor Vessel Head Penetration No. 56 at SONGS Unit 3**

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## 1.0 INTRODUCTION

Four indications have been discovered in the SONGS Unit 3 reactor vessel head penetration tubes. Consideration is being given to using the embedded flaw repair method for each indication. These indications are all located on the OD of the CEDM penetration tubes, in the vicinity of the J-groove weld as it intersects with the tube. All but one of these indications [1] fall within the repair guidelines approved by the NRC in an SER dated July 3, 2003, as documented in WCAP-15987-NP, Rev 2-NP-A [2].

The one indication which does not fall within the guidelines is in penetration 56, and has the following dimensions:

- Depth = 0.513 in.
- Length = 1.96 in.
- Thickness of tube = 0.661 in.

This indication has a depth to thickness ratio of 0.776, which slightly exceeds the limit used in the topical report of 0.750. This limit is used in Section XI to ensure protection against leakage, rather than a calculated limit. In this report, calculations have been completed to show that the ASME code margins can be maintained with much deeper flaws. This evaluation has been carried out to determine whether it is acceptable to use the embedded flaw repair technique on this indication.

### 1.1 ASME CODE ACCEPTANCE CRITERIA

The evaluation procedures and acceptance criteria for indications in austenitic piping are contained in paragraph IWB 3640 of ASME Section XI [3]. Although there are no specific guidelines presently in Section XI for repair of head penetrations, the approach of IWB 3640 will be using here.

The first step in the evaluation of the embedded flaw repair will be to determine the maximum allowable flaw which could remain in the head penetration, and which would meet the acceptance margins of Section XI. This flaw size was determined using plastic limit load methodology, as discussed in Appendix C of Section XI.

The applicability of the limit load expression of Section XI was investigated by the Working Group on Pipe Flaw Evaluation, by collection and study of all the pipe fracture experiments to date (about 3000). It was determined that the limit load expressions become progressively more conservative as the radius to thickness ratio of the pipe gets smaller. Conversely, for thin walled pipes, the expression can become non-conservative, so a limitation has been added to Section XI, Appendix C to limit the application of Appendix C to pipes with radius to thickness ratios less than 15. The radius to thickness ratio of the SONGS 3 CEDM tubes is about 2.6, so the expressions apply directly.

In paragraph IWB 3640 of the Code [3], the allowable flaw sizes are defined based on failure load safety margins. For both axial and circumferential flaws, these margins are 2.7 for service

level A, 2.4 for service level B, 1.8 for service level C, and 1.3 for service level D. These margins are consistent with those used in the Topical Report [2], which has been approved. The failure loads, and consequently the allowable flaw sizes, are large for austenitic stainless steel base metal and the Alloy 600 material since they both have high fracture toughness.

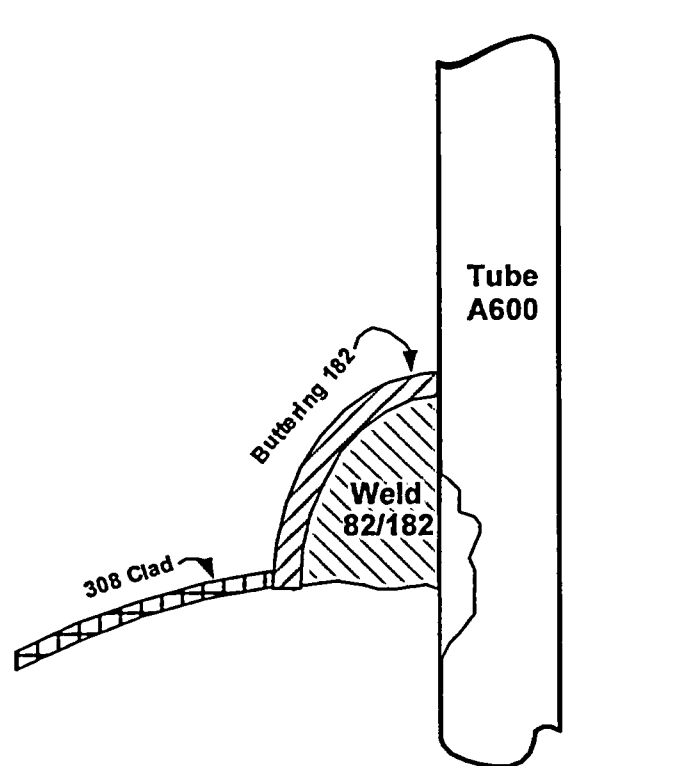
The evaluation process of Section XI continues with a flaw growth analysis, including the requirements for fatigue and stress corrosion cracking. Since the embedded flaw repair will seal the indication from the environment, only fatigue crack growth is appropriate to consider. The methodology for the sub-critical crack growth analysis is described in detail in Section 3, and is unchanged from the previously approved analytical methodology.

## **1.2 GEOMETRY AND SOURCES OF DATA**

The geometry of a typical reactor vessel head penetration is shown in Figure 1-1, along with a sectional schematic of the types of indications which were found. The head thickness for SONGS 3 is 7.625 inches. The head penetration geometries are shown in Table 1-1.

The fatigue crack growth evaluations to be discussed here are based on a detailed three dimensional elastic-plastic finite element analysis completed for the SONGS 2 and 3 head penetrations [4], as will be discussed further in the next section.

<b>Table 1-1 Head Penetration Geometries</b>		
<b>Location</b>	<b>CEDM Tube Thickness (inch)</b>	<b>CEDM Tube OD (inch)</b>
CEDM	0.661	4.05



**Figure 1-1** Typical Configuration of Head Penetration, Showing Indications

## **2. LOADING CONDITIONS AND STRESS ANALYSIS**

### **2.1 TRANSIENT SELECTION**

The requirement for an evaluation of a flaw using the rules of Section XI is that the governing transient for normal and upset conditions be chosen, as well as the governing emergency and faulted condition. As described in Section 1, this is necessary because two separate evaluations are required, utilizing different safety margins. This is to account for the lower probability of occurrence for emergency and faulted transients.

There are many head penetrations in a reactor vessel upper head, and so the highest stressed penetration was chosen for analysis. This is a conservative assumption, since penetration 56 is at an angle of 34.9 degrees, as compared to the outermost penetration, which is at 49.7 degrees.

The thermal transients that occur in the upper head region are relatively mild, because most of the water in the head region has already passed through the core region. The flow in the upper head region is low compared to other regions of the reactor vessel, which also helps to mute thermal transients.

The transients that occur in a typical Combustion Engineering plant are shown in Table 2-1. The detailed analysis was completed on only four transients, because those four were deemed to have the largest contribution to fatigue.

The governing mode of failure for the head penetrations is ductile limit load, so the secondary stresses (thermal and residual) have no impact. The governing transients for the allowable flaw size calculation will then be those with the highest pressure, and those are listed below:

- Level A and B: Reactor Trip
- Level C and D: Large Steam Break

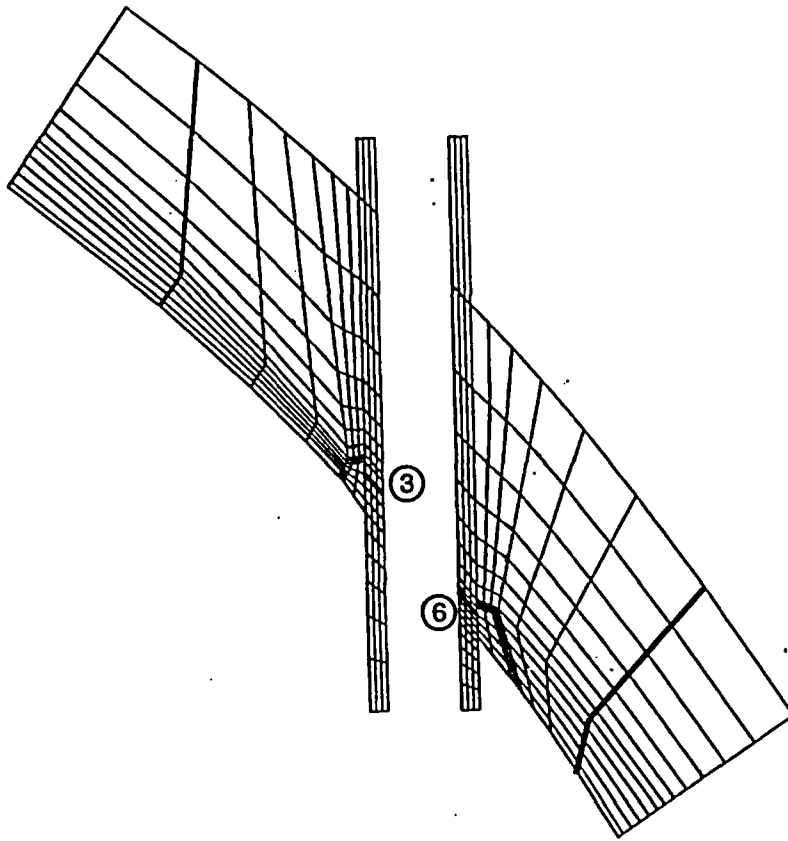
### **2.2 STRESS RESULTS**

The stresses in the closure head region were determined with three dimensional elastic-plastic finite element models, using isoparametric elements [4]. The finite element model and the sections chosen for analysis are shown in Figure 2-1.

The region of the head penetration that has the highest stresses is that nearest the attachment weld (cuts 3 and 6). Of these two locations, cut 3 has higher stresses, and therefore that location was chosen for the analysis. This is an inherent conservatism in the analysis, as will be discussed further below.

Table 2-1 Summary of Reactor Vessel Transients: Typical Combustion Engineering Plant		
Number	Transient Identification	Number of Occurrences
	<i>Normal Conditions</i>	
1	Heatup and cooldown at 100°F/hr	500
2	Load follow cycles (Unit loading and unloading at 5% of full power/min)	15,000 (5000 used)
3	Step load increase and decrease of 10% of full power	10,000
4	Steady state fluctuations	3,000,000
	<i>Upset Conditions</i>	
5	Loss of load, without immediate turbine or reactor trip	40
6	Loss of flow (partial loss of flow, one pump only)	40
7	Reactor trip	400
	<i>Test Conditions</i>	
8	Primary side hydrostatic leak test conditions	200
9	Cold hydrostatic test @ 3105 psig	10
	<i>Emergency Faulted Conditions</i>	
10	Large loss of coolant accident (LOCA)	1
11	Large steam line break (LSB) (other transients described in Section 4)	1
12	Safe shutdown earthquake	1
13	Loss of secondary pressure (emergency)	5

Note: Transients 1, 2, 3 & 7 were used in the analysis.



**Figure 2-1    Finite Element Model, with Analytical Cross Sections Identified**

### 3.0 FRACTURE ANALYSIS METHODS AND MATERIAL PROPERTIES

The fracture evaluation was carried out using the approach suggested by Section XI Appendix C [3], and is consistent with the approach used in the approved Topical Report [2].

#### 3.1 STRESS INTENSITY FACTOR CALCULATIONS

One of the key elements of a fracture evaluation is the determination of the driving force or stress intensity factor ( $K_I$ ). This was done using equations available in the literature. The stress profile was approximated by a cubic polynomial:

$$s(x) = A_0 + A_1x + A_2x^2 + A_3x^3$$

where:

x	=	coordinate distance into the wall, inch
$\sigma$	=	stress perpendicular to the plane of the crack, ksi
$A_i$	=	coefficients of the cubic fit

The stress intensity factor calculation for an embedded flaw was taken from the work by Shah and Kobayashi [5] which is applicable to an embedded flaw in a semi-infinite medium, subjected to an arbitrary stress profile.

$$K_I = \frac{M_o}{I} \left[ \frac{\pi b}{a} \right]^{0.5} (b^2 \cos^2 \theta + a^2 \sin^2 \theta)^{0.25} \left[ \frac{c}{E(k)} - \frac{k^2 b \sin \theta}{(1+k^2)E(k) - k'^2 K(k)} \right]$$

where:

$M_o$	=	applied bending moment
I	=	moment of inertia
b	=	semi-minor axis of the ellipse
a	=	semi-major axis of the ellipse
$\theta$	=	angle in the parametric equations of the ellipse
c	=	distance from centerline of the wall to centerline of the flaw
$E(k)$	=	complete elliptic integral of the second kind
$K(k)$	=	complete elliptic integral of the first kind
k, k'	=	modulus and complimentary modulus of Jacobian elliptic functions

This expression has been shown to be applicable to embedded flaws in a thick-walled pressure vessel, through the use of finite element models with actual cracks modeled, as shown in a paper by Lee and Bamford [6].

#### 3.2 FRACTURE TOUGHNESS

The other key element in a fracture evaluation is the fracture toughness of the material. The fracture toughness has been taken directly from the work by Brown and Mills [7], because no

reference values are yet available in Section XI, for Ni-Cr-Fe alloys. The fracture toughness for the Alloy 600 is at least equivalent to that of 304 or 316 stainless steel, which guarantees that any possible failure will be by ductile limit load.

### 3.3 FATIGUE CRACK GROWTH PREDICTION

The analysis procedure involves postulating a flaw in the head penetration, subject to a series of design loads. The fatigue loadings in the head penetration region are very mild. The applied loads include pressure, thermal transients and residual stresses. The thermal transients used for this evaluation are the plant heatup and cooldown, load follow cycles, step load increase/decrease, and reactor trip. The complete list of design transients for this location is provided in Table 2-1, but the transients used in the evaluation comprise the limiting ones for fatigue crack growth.

The cycles were distributed evenly over the entire plant design life (40 years). The stress intensity factor range,  $\Delta K_I$ , that controls fatigue crack growth, depends on the geometry of the crack, its surrounding structure and the range of applied stresses in the region of the postulated crack. Once  $\Delta K_I$  is calculated, the fatigue crack growth due to a particular stress cycle can be determined using a crack growth rate reference curve applicable to the material of the head penetration nozzle.

The crack growth rate (CGR) reference curves for these nickel base alloys have not been developed for Section XI in the Code, therefore information available from the literature was used. Based on the results reported in Reference 8, a crack growth rate curve was developed for application in the air environment for Alloy 600 material, as shown below.

$$\frac{da}{dN} = CS_R \Delta K^n$$

$$C = 4.835 \times 10^{-14} + 1.622 \times 10^{-16} T - 1.490 \times 10^{-18} T^2 + 4.355 \times 10^{-21} T^3$$

$$S_R = [1 - 0.82R]^{2.2}$$

$$n = 4.1$$

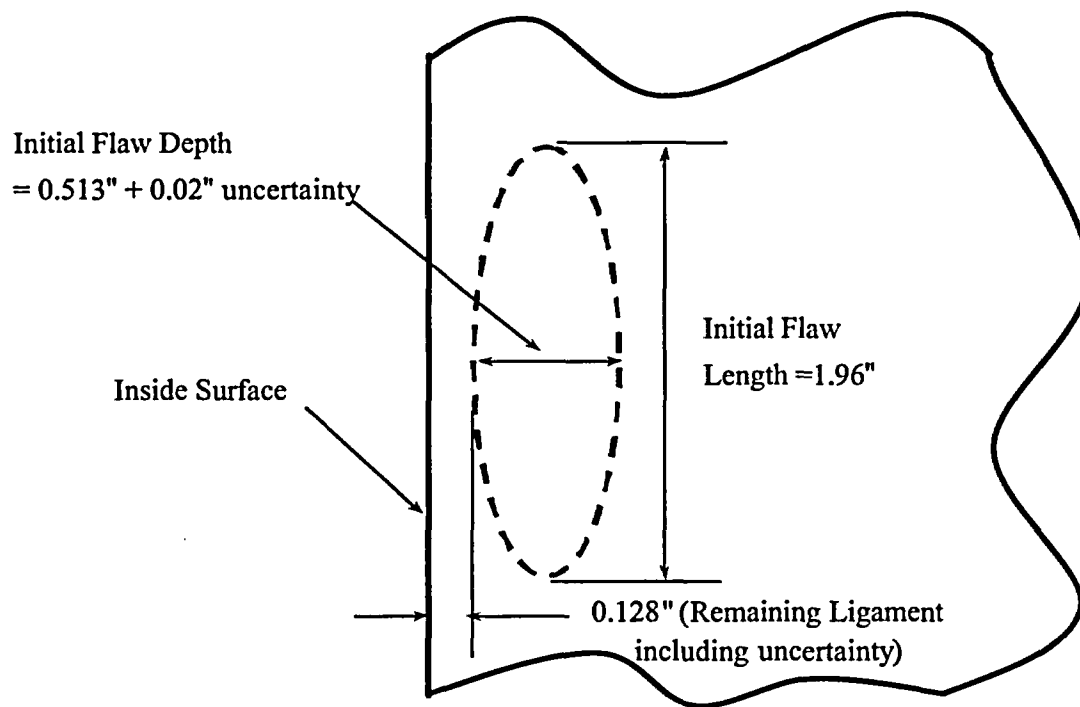
where:

T	=	Average temperature of the transient, (°C).
$\Delta K$	=	Stress intensity factor range, (MPa $\sqrt{m}$ ).
R	=	Stress Intensity Ratio, (K min/K max).
da/dN	=	Fatigue crack growth rate ( m/cycle).

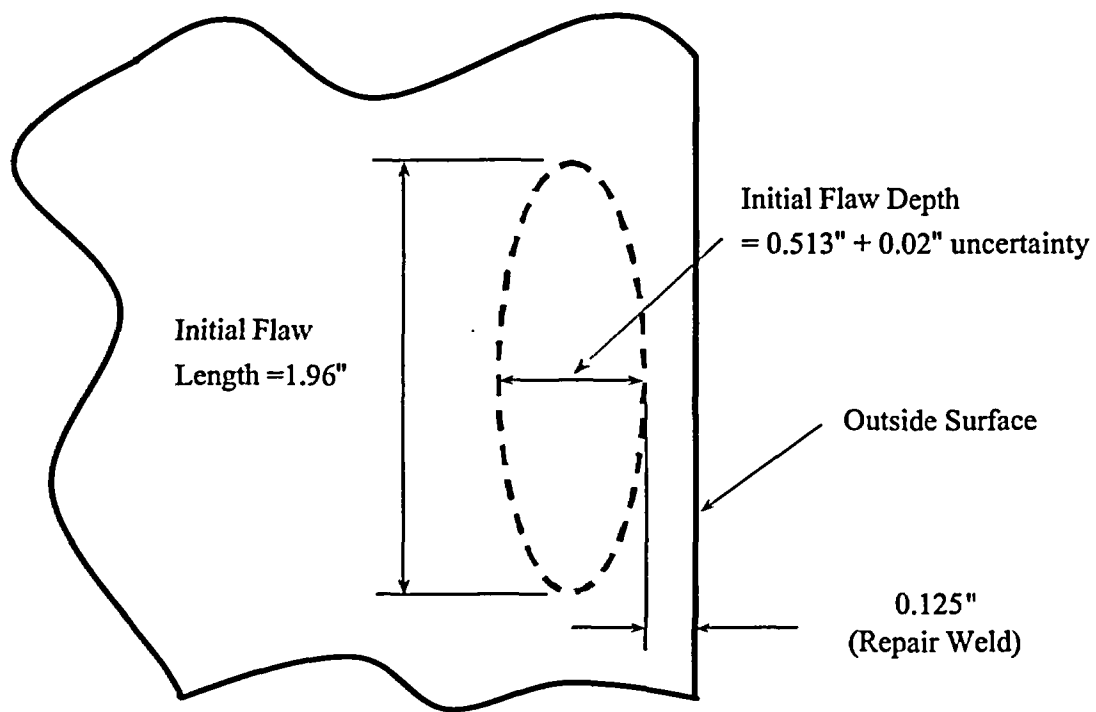
The crack growth rate reference curve in air for the repair weld Alloy 52 is not available. There are 4 tests on Alloy 52 in PWR water environment. The available data in reference [8] showed

Alloy 52 and Alloy 600 have the same growth rate in PWR Water environment. Therefore, Alloy 600 growth rate in air can be used as the Alloy 52 growth rate in air.

Once the incremental crack growth corresponding to a specific transient, for a small time period, is calculated, it is added to the original crack size, and the analysis continues to the next time period and/or thermal transient. The procedure is repeated in this manner until all the significant analytical thermal transients and cycles known to occur in a given period of operation have been analyzed.



**Figure 3-1 Sketch of Model Used for Fatigue Crack Growth Evaluation, for Propagation Near the Tube Inside Surface**



**Figure 3-2 Sketch of Model Used for Crack Propagation Through the Embedded Flaw Repair Weld**

## **4.0 FRACTURE EVALUATION RESULTS**

### **4.1 ALLOWABLE FLAW SIZE DETERMINATION**

The first step in the evaluation is to compare the actual flaw depth to the maximum allowable depth necessary to maintain the ASME Code margins. To do this we will use the calculation model for the plastic limit load for an axial surface flaw, as given in Section XI Appendix C. In making this calculation we have used the actual yield strength and ultimate tensile strength of the tube material from the Certified Material Test Report [9].

The aspect ratio of the indication, length/depth is about 3.8, so a value of 4.0 was used in the calculation. The results are shown in Figure 4-1, for Level A conditions, and show that the allowable depth, maintaining the ASME Code margin of 2.7, is 89.5 percent of the wall thickness. The results for Level B conditions are slightly more limiting, even though the code margin for Level B is only 2.4. The pressure is slightly higher for some upset conditions, so the allowable depth is 89% of the wall thickness (Figure 4-2).

The next step in the evaluation is to determine the useful life of the repair. This involves a fatigue crack growth evaluation to predict the future growth of the flaw in the remaining ligament of the penetration material, as well as a similar evaluation to predict the growth of the flaw into the embedded flaw repair weld. No stress corrosion cracking calculations are necessary because the embedded flaw repair seals the flaw from the environment.

### **4.2 FATIGUE CRACK GROWTH RESULTS**

Results were obtained for two different situations, the first being crack growth into the remaining ligament of the tube, and the second being growth into the embedded flaw repair weld. The first case is illustrated by the sketch in Figure 3-1, and the second is illustrated by the sketch in Figure 3-2.

In the first case, the objective was to determine the future growth of the existing indication after the embedded flaw repair is applied. Since the flaw will be sealed from the primary water environment, the only mechanism of growth is fatigue. Two different aspect ratios were used in the evaluation, to show the sensitivity of the results to flaw shape. The aspect ratio is defined in this case as the ratio of the flaw length to the flaw width. The aspect ratio of four corresponds to the indication as found, while the aspect ratio of 50 is a very conservative upper bound.

The depth of the flaw was assumed to be the as-detected depth of the indication, plus an uncertainty. The upper bound on the uncertainty is 0.020 inch, as determined by an extensive review of the NDE methodology used in this examination. At SONGS, the calibration block had a notch that was 0.129" from the ID surface. This notch measured as 0.148" using the TOFD calibration. The indication in nozzle #56 measured as 0.148" using the same calibration. This results shows that at this point on the curve, the uncertainty of the TOFD measurement is 0.019". Accordingly, a 0.020" uncertainty is appropriate to apply for engineering analysis of this indication.

The crack growth results for the first case, growth into the remaining ligament, are shown below, and show that the crack growth is very small.

<b>Crack Growth into the Remaining Ligament (0.128 in)</b>					
	<b>Initial Half Crack Depth (inch)</b>	<b>Half Crack Depth (inch) After</b>			
		<b>3 year</b>	<b>6 year</b>	<b>10 year</b>	<b>15 year</b>
Aspect ratio = 4	0.2665	0.2722	0.2778	0.2854	0.2949
Aspect ratio = 50	0.2665	0.2742	0.2818	0.2920	0.3048

	<b>Initial Half Crack Depth (inch)</b>	<b>Crack Growth (inch) After</b>			
		<b>3 year</b>	<b>6 year</b>	<b>10 year</b>	<b>15 year</b>
Aspect ratio = 4	0.2665	0.0057	0.0113	0.0189	0.0284
Aspect ratio = 50	0.2665	0.0076	0.0153	0.0255	0.0383

A second crack growth calculation was carried out to predict crack growth that might occur in the embedded flaw repair weld itself. The methodology used is the same as that used for the first case, except that the growth prediction is in the opposite direction. The results of this calculation also show that the growth is very small, and are tabulated below.

<b>Crack Growth into the Repair Weld (0.125 in)</b>					
	<b>Initial Half Crack Depth (inch)</b>	<b>Half Crack Depth (inch) After</b>			
		<b>3 year</b>	<b>6 year</b>	<b>10 year</b>	<b>15 year</b>
Aspect ratio = 4	0.2665	0.2701	0.2736	0.2784	0.2851
Aspect ratio = 50	0.2665	0.2713	0.2760	0.2824	0.2904

	<b>Initial Half Crack Depth (inch)</b>	<b>Crack Growth (inch) After</b>			
		<b>3 year</b>	<b>6 year</b>	<b>10 year</b>	<b>15 year</b>
Aspect ratio = 4	0.2665	0.0036	0.0071	0.0119	0.0186
Aspect ratio = 50	0.2665	0.0048	0.0095	0.0159	0.0239

#### 4.3 CONSERVATISMS IN THE EVALUATION

The fracture evaluation was based on the stresses in the outermost penetration, at an angle of 49.7 degrees, which are known to be higher than those of the actual penetration, which is at 34.9 degrees. Also, the stresses on the uphill side of the penetration were used (cut 3) as opposed to the lower stresses on the downhill side (cut 6), where the indication is actually located.

The indication was modeled with an aspect ratio (length/depth) of 4, which is slightly more conservative than the actual aspect ratio of 3.8. Acceptable results were also obtained for a much more conservative aspect ratio of 50. Uncertainty in the NDE measurements was also added to the indication size for the evaluation, both for the crack growth and the final allowable flaw size, adding further conservatism, as shown in Figure 4-3.

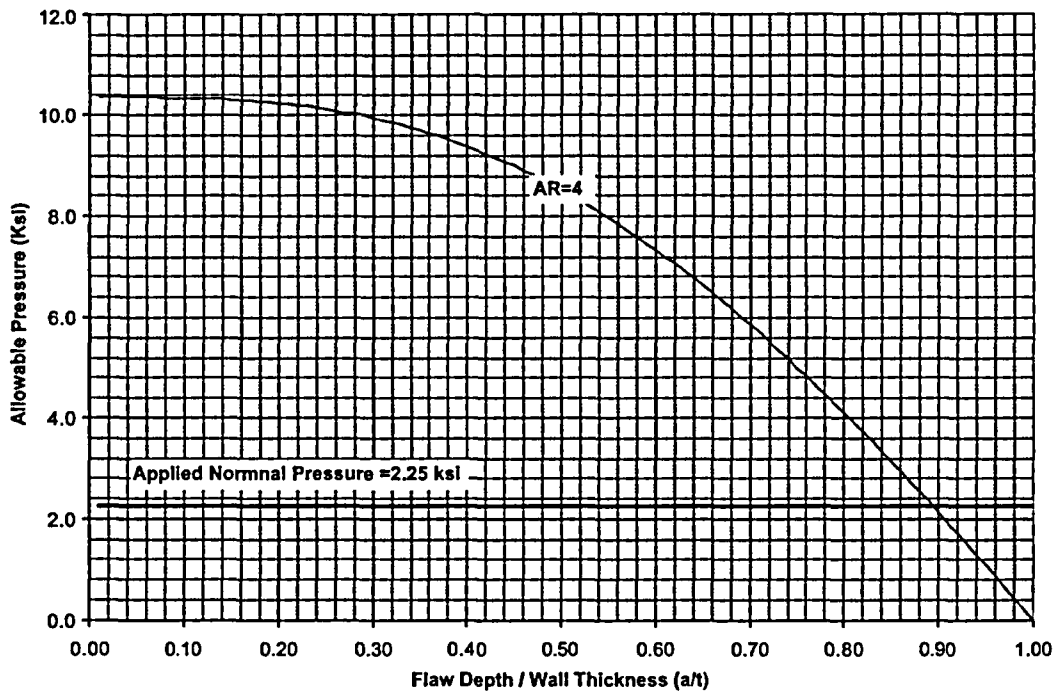
#### **4.4 RESULTS AND DISCUSSION**

The indication in penetration 56 has been evaluated for potential repair using the embedded flaw repair technique. The as-found indication is slightly larger than the maximum size evaluated in the Topical Report, WCAP-15987-NP, in that it has a nominal depth of 77.6 percent of the thickness as compared to the 75 percent value used in the WCAP. Investigation of the actual margins required by the ASME Code Section XI shows that the indication could be as deep as 89 percent of the wall thickness and still meet the Code margins.

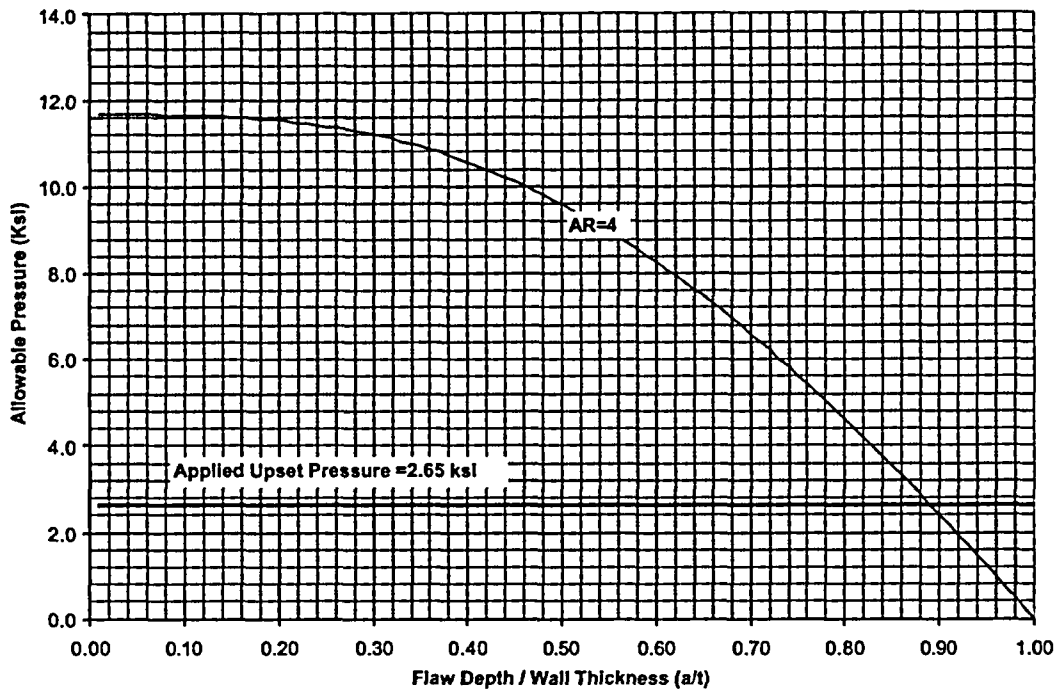
The fatigue crack growth results were developed including the upper bound inspection uncertainty of 0.020 inch. The results show that the indication would grow by only a small amount into the remaining ligament for the coming years. The indication will grow about 0.0113 inch in six years, about 0.0189 inch in ten years and still remains within the acceptable limit of 89 percent of the wall. For potential growth through the embedded flaw repair weld, the flaw will grow a distance of 0.0071 inches into the repair weld in six years, and 0.0119 inches into the repair weld in ten years.

These results are incorporated into the allowable flaw depth in Figure 4-3, where the results with the maximum uncertainties are shown. With the maximum uncertainty, the indication remains within the ASME Code margins for at least 14 years. The longer assumed flaw remains within the acceptable margins for at least 10 years.

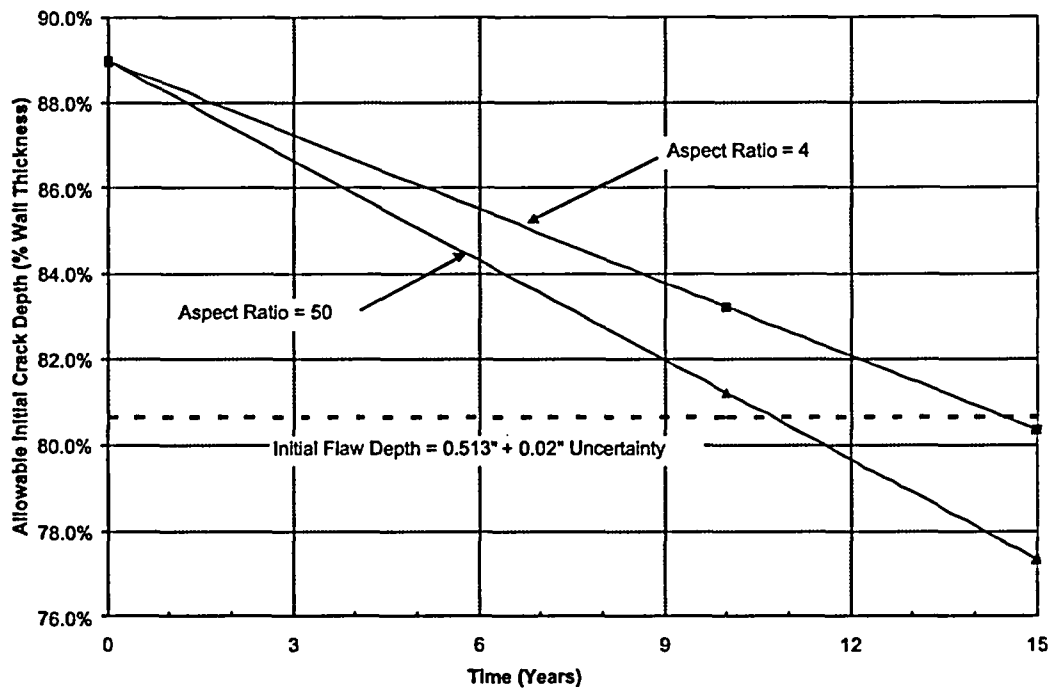
Using the best estimate indication size for the as-found indication (77.6 percent of the wall thickness) with an aspect ratio of four, the indication would remain within the Code margins for a very long period of time, in excess of 18 years. Therefore it may be concluded that the existing indication in penetration 56 is acceptable to repair using the embedded flaw repair method.



**Figure 4-1 Allowable Axial Part-Through Flaw Depth for CEDM 56, Level A Conditions (SF = 2.7)**



**Figure 4-2 Allowable Axial Part-Through Flaw Depth for CEDM 56, Level B Conditions (SF = 2.4) [Limiting Case]**



**Figure 4-3 Results of Allowable flaw Size Calculation, Including Fatigue Crack Growth, and Consideration of Uncertainties**

## 5.0 REFERENCES

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